CP-Violation in the R-Parity Violating Minimal Supersymmetric Standard Model: Muon Decay

Peter Herczeg (T-16); ***herczeg@lanl.gov***

Although the CP-violating (CPV) effects [1] observed in the decays of the neutral K- and B-mesons can be accounted for by the Kobayashi-Maskawa phase δ_{KM}, the existence of new sources of CPV remains one of the major questions in the field. New CPV interactions are present in many extensions of the Standard Model (SM). It is also relevant to mention in this connection, that δ_{KM} is not sufficient to generate the baryon asymmetry of the universe.

One of the best motivated extensions of the SM are supersymmetric models, the simplest of which is the Minimal Supersymmetric Standard Model (MSSM) [2]. Already in the MSSM, which has the same gauge group as the SM, the conservation of lepton-number (L) and baryon number (B) is (unlike in the SM) not automatic: the superpotential can contain renormalizable and gauge invariant L- and B- violating terms. A problem that arises in this connection is that some of the interactions induced by these terms must be extremely weak to prevent too rapid proton decay. In the MSSM the solution chosen is to eliminate all the L- and B-violating couplings by requiring invariance under R-parity (a discrete symmetry). Alternatively, one can forbid only the dangerous terms (by assuming invariance under a different discrete symmetry) or accept that they are as small as required. The MSSM which includes R-parity violating couplings is usually termed as the R-parity Violating MSSM ($\not{R}MSSM$).

The MSSM contains new CPV phases. In the $\not{R}MSSM$ the R-parity violating couplings are CPV in general, and thus represent additional new sources of CPV. The most suitable observables to probe the existence of new CPV interactions are those for which the contribution from δ_{KM} is small. In an earlier study [3] we analyzed the contributions from R-parity violating interactions to parity and time-reversal violating electron-nucleon interactions, which can be probed through searches for the electric dipole moments of atoms and molecules. Here we report on an investigation of CP-violation from the R-parity violating interactions in the dominant decay of the muon, $\mu^+ \to e^+ \nu_e \bar{\nu}_\mu$ [4].

In muon decay CPT invariant CPV interactions can be probed through the time-reversal (T) -odd correlation $\vec{\sigma}_\mu \cdot \vec{p}_e \times \vec{\sigma}_e$ in the decay probability. Here $\vec{\sigma}_\mu$ and $\vec{\sigma}_e$ are the spin of the muon and the electron, and $\vec{p}_e$ is the electron momentum. This correlation is governed by the so called α', and β' parameters [5]. The contributions to α' and β' from final state interactions, which can mimic T-violation, are negligible since they are due to the weak interaction.

In lowest order in new muon decay interactions $\alpha' = 0$, and β' arises from the interference of the SM muon decay interaction and a scalar-pseudoscalar type interaction of the form

$$H^S_{RR} = \frac{G_F}{\sqrt{2}} g^S_{RR} \bar{e}\left(1-\gamma_5\right)\nu_e \bar{\nu}_\mu \left(1+\gamma_5\right)\mu + H.c. \quad (1)$$

(G_F= Fermi constant), and is given by

$$\beta' = 4\,\mathrm{Im}\, g^S_{RR} \,. \quad (2)$$

A search for the $\vec{\sigma}_\mu \cdot \vec{p}_e \times \vec{\sigma}_e$ correlation yielded $\beta' = \left(4.8 \pm 12.8\right) \times 10^{-2}$ [6], implying

$$\left|\mathrm{Im}\, g^S_{RR}\right| < 6.5 \times 10^{-2} \qquad \left(90\%\, c.l.\right). \quad (3)$$

About the same limit follows from data on T-even muon decay observables [5]. A new experiment under way at the Paul Scherrer Institute in Switzerland aims to improve the sensitivity to β' by an order of magnitude [7].

Inspection shows that the R-parity violating couplings give rise to a muon decay interaction of the form (1), mediated by the $\tilde{\tau}_L$ (see Fig. 1) [8]. The corresponding constant g^S_{RR} is given by $g^S_{RR} = -\lambda_{131}\lambda^*_{232}\omega / 4m^2_{\tilde{\tau}_L}$, where λ_{131}, λ_{232} are coupling constants, $m_{\tilde{\tau}_L}$ is the mass of the $\tilde{\tau}_L$, and ω is a product of fermion mixing

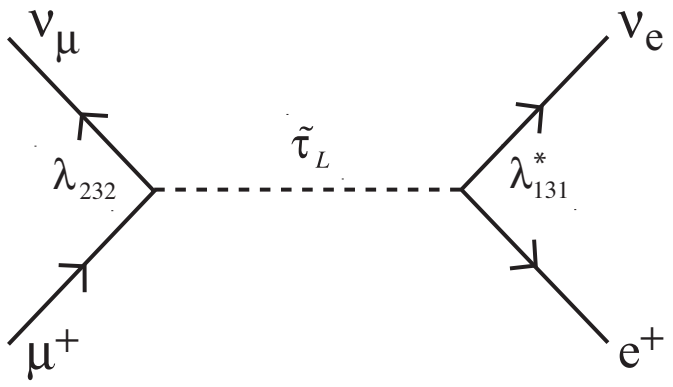

Figure 1— The contribution to g^S_{RR} from the R-parity violating interactions.

matrix elements. The limit (3) on β' sets a limit

$$\left|\mathrm{Im}\left(\lambda_{131}\lambda^*_{232}\omega\right)\right| < 2.2\times10^{-2}\left(m_{\tilde{\tau}_L}/100\,GeV\right)^2 \quad (4)$$

on the CPV product of the coupling constants.

From an analysis of the constraints on $\left|\mathrm{Im}\left(\lambda_{131}\lambda^*_{232}\omega\right)\right|$ from other sources we find that the best present limit comes from the experimental bound [9] on the electric dipole moment of the electron (d_e). The λ_{131} and λ_{232} couplings contribute to d_e through two-loop diagrams. We find that for $m_{\tilde{\tau}_L}$ in the range of 100 GeV to 1 TeV the limits on $\left|\mathrm{Im}\left(\lambda_{131}\lambda^*_{232}\omega\right)\right|$ from d_e are more stringent than (4) by 2 to 3 orders of magnitude.

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